August 15, 1996

EPA-SAB-EEC-96-004

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

Subject: Review of the Waste Incineration Research Program

Dear Ms. Browner:

At the request of the Office of Research and Development (ORD), the Waste Incineration Subcommittee of the Environmental Engineering Committee (EEC) of the Science Advisory Board reviewed the Agency's Waste Incineration Research Program. The Subcommittee met September 11-13, 1995 at the National Risk Management Research Laboratory (NRMRL), Air Pollution Prevention and Control Division, Research Triangle Park, North Carolina. The EEC approved the Subcommittee's report May 21, 1996 and the Executive Committee approved this report June 25, 1996.

The research had been conducted by the Air and Energy Engineering Research Laboratory and the Risk Reduction Research Laboratory which are now consolidated into the National Risk Management Research Laboratory. The charge for the review was to:

a) Review the importance of the issues identified for work in the future, namely formation, control, and monitoring of products of incomplete combustion (PICs), including dioxins, metal transformation and control; and waste combustion and emission characterization. Review the integration of this research with any existing research programs.

b) Review the integration of the program in terms of past work and plans for future work which will address the issues stated above and obtain the needed research information.

c) Evaluate the effectiveness of in-house research on meeting short-term and long-term issues and needs.

Combustion is a major part of society. We are dependent upon combustion processes for a variety of reasons, including power generation, transportation, waste destruction (incineration), and in some cases heating. Therefore, understanding the emissions from these systems could result in actions that reduce emissions and in effect reduce adverse health effects. The Subcommittee considers this to be an important factor in recommending that the research continue in an integrated fashion to address the ever-increasing complexity of combustion issues, including those dealing with incineration of wastes.

The key findings and recommendations of the Subcommittee, based on the above statement and review of the projects, are:

a) The Subcommittee concluded that the EPA laboratory has world-class facilities and the Agency staff has a demonstrated record of productivity and accomplishment, which has earned the respect of their peers. However, the low research and development to capital equipment budget ratio implies that people and ideas are secondary to instrumentation. Although research goals for the funded projects are being adequately addressed, they represent short-term projects and this leads to a lack of coherent, focused research to address the complex problems.

b) The Subcommittee finds that the program lacks a formal strategic plan. The program also lacks emphasis on the role of incineration in pollution prevention. Two areas that could be addressed are changes in technology to reduce reliance on end-of-pipe control technology and segregating the waste stream to isolate, and perhaps pretreat, constituents known to have negative impact on the emissions from combustion and incineration systems. The Subcommittee recommends that the Agency develop a strategic plan which should incorporate the role of incineration and combustion in pollution prevention.

c) The issues the laboratory is addressing are important and the research projects are obtaining the needed information. The laboratory has successfully collaborated with some outside investigators, and the Subcommittee believes this interaction should be expanded because collaboration provide both research groups with the opportunity to do important research neither could do alone. This was evident by the strengths of the projects which contained some collaboration.

d) Because of the dependence of society on combustion, combustion research should be a core research program.

e) Although the importance of incineration will vary under different policies, maintaining core competency allows the Agency to address unanticipated future problems using an existing base of expertise and science. To be a core research program, funding must be provided to the laboratory to operate as such. Otherwise, marketing to obtain funds outside of EPA may result in a lack of integration in the program. This integration is necessary to address long-term and emerging issues.

f) The research appears to be meeting the short term needs (as evidenced by the interactions with Office of Solid Waste) and most of them will address the long-term combustion related challenges that the Agency is faced with.

In summary, the Subcommittee felt that the laboratory's equipment, facilities and capability are an asset to the Agency, and that it needs to develop a strategic plan, set priorities and follow them.

The Subcommittee appreciates the opportunity to review this program, and looks forward to a written response to its recommendations for the combustion research program.

Sincerely,

Genevieve M. Matanoski

Dr. Genevieve M. Matanoski, Chair
Executive Committee

Dr. Ishwar Murarka, Chair
Environmental Engineering Committee

Jo Ann S. Lighty

Dr. Jo Ann Lighty, Chair
Waste Incineration Subcommittee

ENCLOSURE

NOTICE

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ABSTRACT

The Waste Incineration Subcommittee of the Science Advisory Board reviewed EPA's waste incineration research program. The Subcommittee was asked to: a) review the importance of the issues identified for work in the future, namely formation, control, and monitoring of products of incomplete combustion (PICs), including dioxins, metal transformation and control; and waste combustion and emission characterization. Review the integration of this research with any existing research programs; b) review the integration of the program in terms of past work and plans for future work which will address the issues stated above and obtain the needed research information; and c) evaluate the effectiveness of in-house research on meeting short-term and long-term issues and needs.

The major findings and recommendations of the Subcommittee are: a) The issues the laboratory is addressing are important and the research projects are obtaining the needed information. While the laboratory has interacted with some outside investigators, the Subcommittee believes this interaction should be expanded because collaborations provide strengths in areas where the laboratory does not necessarily have expertise. This was evident by the strengths of the projects which contained some collaboration. b) To be a core research program, funding must be provided to the laboratory to operate as such. It appears as though the marketing to obtain funds outside of EPA resulted in a lack of integration in the program. This integration is necessary to address long-term and emerging issues. The Subcommittee recommends that the laboratory develop a strategic plan which will help determine criteria for judging the projects which are underway (however, this can only occur if operated as a core program). In addition, the strategic planning should incorporate the role of incineration and combustion in pollution prevention. c) The issues appear to be meeting the short term needs (as evidenced by the interactions with Office of Solid Waste) and most of them will address the long-term combustion related challenges that the Agency is faced with. d) Although the importance of incineration will vary under different policies, combustion and incineration research should remain part of the Agency's core research program because of the dependence of society on combustion. Maintaining core competency allows the Agency to address unanticipated future problems using an existing base of expertise and science.

Keywords: combustion, incineration, waste, PICs, metals

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1. EXECUTIVE SUMMARY

On September 11 through 13, 1995, the Waste Incineration Subcommittee met at EPA's National Risk Management Research Laboratory's (NRMRL), Air Pollution Prevention and Control Division (APPCD) to review the hazardous and municipal waste combustion program. The charge was to:

a) Review the importance of issues identified for work in the future, namely the formation, control, and monitoring of products of incomplete combustion (PICS), including dioxins; metal transformation and control; and, waste combustion and emission characterization;

b) Review the integration of the program within the Agency in terms of past work and future work which will address the issues stated above and obtain the needed research information. In addition, review the integration of this research with any existing research programs within other federal agencies, academics, and/or government laboratories.

c) Evaluate the effectiveness of the in-house research on meeting the short-term and long-term issues and needs of the program offices and the agency.

Combustion is an integral part of society. From energy generation to waste disposal, combustion and incineration processes are significant in today's civilization. For example, in the United States, which uses coal chiefly for smelting iron ore and generating electricity, coal production grew 15 percent between 1980 and 1988 and China, which uses coal in both homes and in industry, expects to increase its coal use by 40% over eight years (Brown et al., 1993). Along with the benefits of combustion, there are possible adverse effects. In order to balance the benefits and adverse effects, it is important that research be conducted to develop answers/results which will reduce adverse effects and increase benefits. For this reason, the work at the laboratory is extremely important and should be regarded by the Agency as a core competency area.

In *Future Issues in Environmental Engineering* (USEPA, 1995a), the SAB's Environmental Engineering Committee defined core competencies as, "the essential and distinct scientific and technical capabilities that enable EPA to fulfill its current and future missions. Having core competencies supports EPA's ability to approach regulations in an integrated, efficient, cost-effective and harmonized manner and to address multi-pollutant and multi-media problems with the limited resources that will likely be available to the Agency." Regarding combustion research, including incineration, as a core competency will maintain a base of expertise and scientific knowledge which will allow the Agency to address unanticipated problems. The

Subcommittee finds that several factors limit the development of a core competency in combustion:

a) The base research support is small. Additional support comes from a variety of sources (or ”customers”) both within and outside the Agency (such as the Illinois Clean Coal Institute and the Department of Energy’s (DOE) National Renewable Energy Laboratory). While the outside sources provide funding needed for research, their missions may differ from EPA's with the result that the research funded may not meet EPA’s needs as closely as if EPA had funded the research. The presenters discussed a large number of activities which were in support of the program offices. While these functions are valuable, the emphasis on short-term projects and this also leads toward a lack of a coherent, focused research to address the complex problems.

b) The limitations of the budget have forced the staff to become entrepreneurs and sales people who market outside the Agency for funding. This marketing has resulted in a research program which is sometimes focused on the needs of several funding sources. Potentially, this could cause the program not to focus primarily on EPA’s or the public's needs.

c) The financial support for collaborative efforts with outside researchers is small. The APPCD should be encouraged to participate in truly collaborative research in which EPA and the collaborators are equal partners because collaborative efforts allow both research groups to do important work neither could do alone.

The general findings and recommendations of the Subcommittee are:

a) The issues the laboratory is addressing are important and most of the projects were of value. The research being conducted was high quality; the engineering research staff is exceptionally capable. The combination of outstanding facilities, equipment, and a demonstrated record of accomplishment attests to the capabilities.

b) The research group should foster more interaction with other researchers as opposed to contracts under direct supervision by EPA personnel or independent grant research at universities. The interaction should be truly collaborative research projects where both parties are involved from concept through to completion of the work. Collaboration is important because it allows both research groups to conduct important research neither could do alone.

c) The research group should formalize their strategic plan to help determine criteria for judging the projects which are underway. In addition, the strategic planning should incorporate the role of incineration and combustion in pollution prevention. The current program lacks a pollution prevention component. Prevention can be addressed in two areas: i) changes in technology (for example, low-NOx burners) to reduce the reliance on end-of-pipe control technology; and ii) segregating the waste stream to isolate, and perhaps pretreat, constituents that are known to have a negative impact on the emissions from combustion and incineration systems. The impact of the effect of changing waste streams, a result of waste minimization and pollution prevention activities, needs to be investigated with regard to its potential impact on the emissions from these systems.

d) The Agency should consider the combustion program, of which waste incineration is a part, as a “core competency” and support it as such. Although the importance of incineration will vary under different policies, combustion and incineration research should remain part of the Agency's core research program because of the dependence of society on combustion. Providing the necessary funding will allow this group to continue to meet these long-term needs as well as the short-term needs of the Agency.

e) The SAB's Research Strategies Advisory Committee (RSAC) should look at the low research & development to capital equipment budget ratio and determine if the present ratios are acceptable to enable the program to continue with viable projects and equipment.

2. INTRODUCTION

2.1 Background and History of the Research Program

The Air and Energy Engineering Research Laboratory, Combustion Research Branch (CRB) has provided fundamental and applied combustion research since the 1960s (USEPA, 1984). During this time the emphasis was placed on the control of nitrogen oxides using combustion modifications. In 1983, CRB was asked to provide fundamental research support to the Hazardous Waste Engineering Research Laboratory. At this time, several combustors were upgraded and/or built to perform the necessary studies. In June 1988, the laboratory stopped work to obtain a RCRA permit for the facilities. This was received in November 1989. In 1986, CRB was funded to perform field tests on numerous Municipal Solid Waste (MSW) Combustors to support the development of regulations for these systems by the Office of Air Quality Planning and Standards (OAQPS). From 1987 until 1992, field data were obtained and it was decided to build a new multi-fuel combustor to perform in-house tests. This unit was completed in 1995.

At the present, facilities include: rotary kiln incinerator simulator, package boiler simulator; commercial package boiler; horizontal tunnel furnace; dual-stage fluidized bed combustor; Resource Conservation and Recovery Act (RCRA) Permitted Air Pollution Control System; and, the Multi-fuel Stoker Combustor Research Facility. The laboratory has also developed methods for dioxin analysis and has numerous analytical capabilities. With these tools, the laboratory has developed the capability to investigate a variety of combustion and incineration issues, but they have not yet adequately applied these capabilities.

The engineering research staff of APPCD's Air Pollution Technology Branch is exceptionally capable. The combination of outstanding facilities, equipment, and a demonstrated record of accomplishment qualifies this laboratory to be a first class research facility. The Subcommittee recognizes their contribution to the field of combustion, as demonstrated by: a) 139 technical papers; b) over a dozen patents; c) nine EPA Scientific and Technological Achievement Awards (including a Level I award and multiple awards at Level II); d) EPA Gold, Silver, and Bronze medals; e) the PHS Meritorious Service Medal; and f) the Fitzhugh Green Award (for demonstrating outstanding leadership skills and ability in creatively devising and implementing major programs overseas). The group has contributed to several important air pollution issues; specifically, the early work from CRB contributed to the understanding of NOx control strategies and has improved our ability to utilize high nitrogen fuels within clean air regulations. The group is to be commended for their accomplishments to the EPA and society.

With the reorganization of the Office of Research and Development (ORD), the Air and Energy Engineering Research Laboratory (AEERL) was merged with other laboratories to become part of the National Risk Management Research Laboratory. The function of this new laboratory is to perform "research and technology transfer to prevent, mitigate, and control pollution."

2.2 The Review and Charge

On September 11-13, 1995, the Waste Incineration Subcommittee met at the National Risk Management Research Laboratory's (NRMRL), Air Pollution Prevention and Control Division (APPCD) to review the hazardous and municipal waste combustion programs. The Subcommittee was charged to:

a) Review the importance of issues identified for work in the future, namely the formation, control, and monitoring of PICs, including dioxins; metal transformation and control; and, waste combustion and emission characterization;

b) Review the integration of the program within the Agency in terms of past work and future work which will address the issues stated above and obtain the needed research information. In addition, review the integration of this research with any existing research programs within other federal agencies, academics, and/or government laboratories.

c) Evaluate the effectiveness of the in-house research on meeting the short-term and long-term issues and needs of the program offices and the agency.

A full listing of the review documents can be found in Appendix A.

3. GENERAL EVALUATION

3.1 Response to the Charge

In response to the charge, the Subcommittee felt that the issues identified were important for work in the future. The projects presented, for the most part, addressed the same issues stated above and will obtain the needed research information. The laboratory has obtained outside funding from a variety of sources; while this funding has been useful in some cases to address issues, it has also resulted in a lack of integration in the program. A recommendation for formalization of a strategic plan follows. The laboratory has collaborated with other researchers in the area, but this collaboration has been minimal. It is evident from the project review, that in the cases where there was collaboration, it was extremely useful in obtaining expertise that the laboratory did not have. The laboratory has responded to the needs of the program offices in a variety of projects; however, these projects are often short-term in nature and the laboratory is having difficulty maintaining the base funding necessary to maintain a core competency which would enable it to address more long-term issues and needs.

The issue of core competency is discussed further below and an evaluation of each project as it responds to the charge is given in Section 4.

3.2 Rationale and Justification for a Core Competency

The Subcommittee views the EPA Incineration Research Program as an important resource for understanding and controlling pollution. The program extends beyond incineration (the combustion of wastes) since the capabilities can be applied to all combustion of fuels. This capability is significant in an age where combustion is so much a part of our society--from electricity generation to transportation and the production of goods. Since combustion is so much a part of our society, there must be a balance between the benefits of the processes versus adverse affects. For this reason, combustion research cannot be ignored, but must be performed to understand and reduce emissions. Since the EPA has a mission to protect the environment by identifying sources and methods of pollution control, a portion of EPA's research program should be devoted to combustion-type research; specifically, this charge falls upon the APPCD (as discussed previously).

Two previous Science Advisory Board (SAB) reports have identified the needs for core competencies. The SAB's 1988 Report, *Future Risk* (USEPA, 1988) makes ten major recommendations to the Agency. The first recommendation is that the EPA should focus on preventing the generation of pollution. The second recommendation is that EPA should implement long-term research programs in areas where it has unique

responsibilities and capabilities.[1] This report further identifies candidate core research areas, including combustion and thermal destruction. The second report, the Environmental Engineering Committee's *Future Issues in Environmental Engineering* (USEPA, 1995a), is part of the cross-SAB futures project which produced *Beyond the Horizon: Protecting the Future with Foresight* (USEPA, 1995b). While this 1995 report does not identify candidate core competency areas, it defines core competencies and their benefits as "...the essential and distinct scientific and technical capabilities that enable EPA to fulfill its current and future missions. Having core competencies supports EPA's ability to approach regulations in an integrated, efficient, cost-effective and harmonized manner and to address multi-pollutant and multi-media problems with the limited resources that will likely be available to the Agency."

In order to define and maintain a "core competency" in combustion research this group will need to anticipate the longer term needs and structure their program to address both the short- and long-term time horizons. The emphasis on long-term research is critical; short-term, regulatory office-driven research will not provide sustainable competence. Some trends can already be identified, such as:

a) Fuels and wastes will become more complex and compositions of these streams will change. While coal is a complex fuel, there is a move to use the energy from more complex heterogeneous fuels such as waste materials, biomass, etc. In addition, as industry increases its waste minimization effectiveness, the composition of the combustible hazardous waste stream will change. In parallel, as municipal recycling increases, the composition of the solid waste stream will also change.

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[1] **Selected Quotes from SAB Reports**

The SAB's 1988 report, *Future Risk* (USEPA, 1988) makes ten major recommendations to the Agency (page 5). The first is:

> "EPA should shift the focus of its environmental protection strategy from end-of-pipe controls to preventing the generation of pollution. EPA should use a hierarchy of policy tools that support national efforts to 1) minimize the amount of wastes generated; 2) recycle or reuse the wastes that are generated; 3) control the wastes that cannot be recycled or reused; and 4) minimize human and environmental exposures to any remaining wastes."

The second is:

> "To support this new strategy, EPA should plan, implement, and sustain a long-term research program. In conjunction with EPA's program offices and the external scientific community, EPA's Office of Research and Development should develop basic core research programs in areas where it has unique responsibilities and capabilities.

The SAB's 1995 report, *Beyond the Horizon: Protecting the Future with Foresight* (USEPA, 1995b) was supported by studies of the SAB's standing committees. The Environmental Engineering Committee's *Future Issues in Environmental Engineering* (USEPA, 1995a) stated (page 2):

> "Core competencies are the essential and distinct scientific and technical capabilities that enable an organization to fulfill its current and future missions. In the future the Agency will be under increasing pressure to address more efficiently multimedia pollutants from all sources."

Future Issues in Environmental Engineering (USEPA, 1995a) does not identify candidate competency areas, but it does identify the following objectives for a solid core research program (page D-2):

> "1) drive pollutant reduction technology to the limit of technical and economic feasibility; 2) develop the capability to predict the amount of all pollutants present in the effluent streams of all sources; 3) promote pollution prevention and the development of low pollutant technology for existing and new advanced systems; and 4) provide a science and technology base for regulations."

b) The number of types of pollutants of interest will increase and the concentration levels of interest will be lower. For example, PAH (polycyclic aromatic hydrocarbons) and particulate matter are of increasing interest.

c) As more pollutants at lower concentrations become a concern, there will be a need for continuous performance assurance techniques. Through the integration of available continuous emissions monitors and full system performance monitoring and controls, performance assurance of minimal emissions can be found without continuously monitoring all pollutants.

The laboratory has previously identified the need for core competency in combustion (USEPA, 1984), which says: "The Agency can provide a leadership role by formulating and executing a core research program that will solve environmental problems associated with all types of combustion systems, fuels and wastes well into the next century." The Subcommittee concluded that the program was not supported within the Agency as a core competency by noting several limiting factors, namely:

a) The base research support is small and largely limited to base salaries and capital equipment. Support comes from a variety of sources both within and outside of the Agency. The presenters discussed a large number of direct and important assistance activities supplied to OAQPS and Office of Solid Waste (OSW) in developing and implementing new standards for combustion systems. These activities include: the Report to Congress on MWCs; comparative tests on continuous emissions monitors; direct work on dioxin control and PICS; serving on numerous working groups on regulation development and implementation. These functions are a valuable resource for the program offices; however, they are short-term activities. For this group to maintain a core competency, they will need to anticipate longer-term needs and structure their program to address both time horizons. The current budget does not maintain the competency and action should be taken to change this course.

b) To compensate for the lack of consistent Agency support, the research staff has had to become entrepreneurs and sales people. In some cases, search for support outside the Agency further splinters and dilutes research.

c) As a result of the lack of funding, the use of outside expertise is limited. The support for outside research is small. The APPCD should be encouraged to participate in truly collaborative research in which both parties are equal through cooperative agreements or other mechanisms. The APCD should act as both an intellectual as well as a financial partner in the research.

As the EPA Office of Research and Development drafts their long-term strategic plan, the Subcommittee urges them to consider the importance of core competencies in this area, and to secure the means to continue this research[2].

3.3 Positive Outcomes of a Core Competency

By developing a core competency, the Agency can meet short-term Agency goals. Core competencies allow EPA to access tremendous expertise for short-term regulatory and enforcement issues. The benefits of this access are threefold. First, the public benefits from the best technologies protecting their environment. Second, the EPA gains credibility from regulations that are science-based and enforcement that is informed. And third, industry benefits by access to advanced technology that allows them to operate more efficiently. Core competency research provides a cornerstone for capabilities such as predictive modeling and coherent risk management strategies.

Compared to other combustion research programs, the EPA research program's charter is unique. In contrast to strictly fundamental, curiosity-driven initiatives, the EPA program is focused on understanding formation, prevention, and control of pollutants from combustion sources. The EPA program spans fundamental studies on the origin and identity of pollutants, to engineering studies of how pollutants are formed, and on to more applied studies of how to control pollutants. The research program is unique because it combines expertise in fundamental combustion, including reacting mechanisms, with expertise and applications in pollution control. Given proper funding, the program can stay unique and unbiased by not focusing on industry-specific or fuel-specific projects.

The research program also serves as a nucleus for long-term research, where EPA can work side-by-side with other combustion researchers. The laboratory has made some effort toward creative collaborations with University faculty and National Laboratory staff; however, the Subcommittee would like to see this interaction fostered even further to take advantage of others' expertise. As stated previously, the collaborations should be truly “collaborative” where the interactions are a two-way dialog between researchers from concept through execution of the research.

3.4 Need for a Strategic Plan

The Subcommittee recommends that EPA should internally re-evaluate the combustion research on a project-by-project basis and identify the tactical and strategic elements in this program. Strategic planning may also help set priorities between fundamental and applied research and technology development leading to patents and

[2] As this report was being completed, the ORD finalized their Strategic Research Plan (USEPA, 1996a). The SAB's Research Strategies Advisory Committee (RSAC) reviewed the Plan and produced a report on that review (USEPA, 1996b)

licensed technologies. The laboratory should include pollution prevention because there are some pollution prevention aspects to the incineration process and fundamental and applied research is needed in this area.

As the laboratory re-organization is completed, it may be helpful to evaluate projects against well-defined criteria. Such criteria might include: a) technical merit of projects; b) relationship to program and laboratory missions; c) impact of the project; d) political mood of the topic; e) customer(s) served by the project; and f) the program's unique contribution (what is the research program's unique advantage compared to other combustion researchers?)

On a lesser note, the Subcommittee found it difficult to adapt to the research program's convention of stating budgets in terms of only contract and purchase dollars. Budgets do not include EPA staff and management salaries, overhead, and capital equipment. Because all the project costs are not assigned to a project, it is difficult to compare EPA’s incineration research budget to other research programs. The Subcommittee found that there appeared to be a disproportional low R&D to capital equipment ratio in the research program budget. The Subcommittee does not wish to jeopardize capital budgets; however, we recommend that this issue be brought directly to the Science Advisory Board's Research Strategy Advisory Committee to see if this is an effective use of funds.

4. EVALUATION OF PROJECTS

As discussed in the presentation by Dr. Hugh McKinnon, Associate Director for Health at the National Risk Management Research Laboratory, the laboratories are aligned with a risk assessment/risk management approach. The program issues identified by the laboratory can be divided into the following:

a) PIC formation and control (including dioxins)

b) Metal transformation and control

c) Combustion of multi-fuels

The issues identified are in alignment with the approach discussed by Dr. McKinnon and the charge (see section 3.0). The Subcommittee found that the issues were indeed important. The following is, in answer to the charge, a discussion of the projects discussed and how they address the resolution of the issues, the integration of the research with other research programs, and the effectiveness of meeting short-term and long-term issues and needs.

4.1 PIC Formation and Control

Seven projects were presented in this area. Clearly this area is of importance to both the Agency and the public. Dr. McKinnon's indicated that some key risk-based considerations for incineration technology research should be researched, including emissions during startup, shutdown and upset conditions. The projects addressed these needs and some responded directly to Office of Solid Waste (OSW) regulatory development needs. Some collaboration with other investigators was presented; however, this was limited.

4.1.1 Development of a PIC Target Analyte List

This project is an OSW initiative and funded by OSW. The OSW objective was to arrive at a single, comprehensive list of PICS to be analyzed in each hazardous waste incinerator trial burn. The list was to be based on results of a pilot scale test of a single mixture of 14 organic compounds in no. 2 fuel oil. Although the research protocol is appropriate, it is limited in that it does not recognize that incinerator emissions depend on the composition of the waste feed. Since the PIC analyte list that will result from these tests will be applied to all incinerators regardless of their feed, the approach is limiting. The research has shown that inclusion of brominated wastes results in a disproportionate number of brominated PICs. Clearly, if brominated wastes were not included, brominated PICs would not be present and, probably, more chlorinated PICs would be observed. This is an important research result which is not totally

explainable via gas-phase combustion. Brominated compounds are thermally fragile and not expected to survive the high-temperature zones of the incinerator. It may imply that surface catalyzed displacement of chlorine by bromine is occurring in cooler, downstream zones of the incinerator. This point is developed further in the discussion of the CFC combustion project.

A better approach would be to develop a standard mixture of chemicals to spike into every incinerator during a trial burn. The feed components could be developed to

a) be sensitive to each failure mode of incineration (i.e. thermal failure, mixing failure, post-combustion formation);

b) represent different pathways of formation by different classes of chemicals; and

c) address uncertainties in PIC formation based on our current knowledge.

The project does represent the need to develop a combustion "core competency". Without the existing facilities and capable personnel the laboratory could not have responded as quickly to OSW's needs.

4.1.2 Characterization of Secondary Combustion Chamber Performance and Development of Failure Mode Diagnostics

This is a joint project between researchers at the Northeast Hazardous Substance Research Center (NEHSRC) and the EPA. In this project, NEHSRC researchers are attempting to develop kinetic codes to model EPA's pilot-scale rotary kiln data. The project is very ambitious, some might say overly ambitious, as it is not clear that the state-of-the-art in combustion modeling is such that success is likely. However, this is an important step in the right direction and addresses an important need to identify mixing within secondary combustion chambers; further understanding of this mixing could reduce the emissions of PICs.

The results are significant in that they may have identified important deficiencies in our understanding of incineration. Modeling and experimental results differed by as much as 12 orders of magnitude under oxygen rich conditions and 6 orders of magnitude for oxygen starved conditions. The differences were primarily attributed to lack of fuel-air mixing and a lack of the ability to properly treat mixing in the model. However, mixing frequency calculations only account for a maximum of 2-3 orders of magnitude discrepancy. Since the kinetic models give reasonable agreement with flow reactor data, this may imply that the failure of the model is due to temperature effects as opposed to deficiencies in the mechanistic/kinetic or micromixing aspects of the model.

Thus, the Subcommittee suggests that the researchers turn their attention toward better defining the macroscale temperature profile in the combustor as well as microscopic temperature distributions. It is not clear at this point whether the discrepancies are due to insufficient or incorrect experimental temperature measurements or temperature fluctuations due to mixing and energy transfer on the microscale. Possibly a modification of the mixing modeling approach to calculate temperature distributions due to mixing could be developed to address this issue. It is unlikely that parameters other than temperature could cause the large discrepancies observed in the modeling and experimental results. Also, the Subcommittee concluded that the project could benefit from using more fundamental approach as in 4.1.7.

4.1.3 Formation and Control of Chlorinated Dioxins and Furans in Combustion Systems and Modeling of PCD and PCF Congener Profiles from MWC

These projects apply a classical engineering approach to determining the source and mechanisms of dioxins in combustion systems. Originally the work addressed municipal wastes, but more recently has addressed cement kiln combustion of hazardous wastes. In this approach, various suspected dioxin precursors are burned in a down-fired burner and allowed to react with various suspected precursors in a down stream cool zone.

The experimental work has yielded valuable data on the role of gas-phase reactions, catalytic surfaces, copper, and chlorine on the yields of dioxins in combustion systems. It represents some of the best engineering science work performed by EPA. However, the work to this point has not been fundamental enough to delineate the actual chemical/physical mechanism of formation. Because the actual mechanisms of dioxin formation are so poorly understood, it is still highly questionable if pilot scale data can be reliably applied to full scale systems. Consequently, the parametric statistical modeling of the data is not as highly rated. If the mechanisms were known, then the limits and bounds of the model could be applied correctly. Without such knowledge, these empirical fits may lead to entirely inappropriate conclusions.

This discussion is not meant to imply that full-scale testing to derive even more empirical data would be more appropriate. In fact, the variability in full-scale performance is unlikely to result in any meaningful data at all.

In light of the recent dioxin reassessment and combustion strategy, EPA's research in this area is under funded. EPA should form a dioxin combustion research task force to immediately address critical dioxin issues, especially the mechanism of formation and prevention strategies. The troika of environmental research entails study of the origin, mechanism, and control of pollution. The origin, through numerous field tests, is well determined and does not therefore deserve significant further study. Several end-of-pipe control strategies have been identified including carbon filtration

and reducing the temperatures of Electric Static Precipitators (ESP). These methods are reasonably well-proven but costly and should not be further pursued by EPA researchers. In addition, carbon filtration results in a transfer from a gas stream to a solid waste. Instead, the task force should focus on the mechanism of formation and developing methods for in-process prevention. A three to five year effort with substantial funding would be reasonable given the magnitude and complexity of this problem.

Again, this project demonstrated the value of a core competency in combustion by responding to the needs of OSW in a timely manner. This work has been used by OSW in defining some components of the Waste Minimization and Combustion Strategy and the Dioxin Reassessment.

4.1.4 Destruction of CFC's and Other Chlorinated Wastes

This project addressed the destruction of CFCs by controlled incineration. Rather serendipitously, very important results were obtained, as very high yields of PCDD/PCDF were observed (23.8 µg/dscm) when CFC 12 was burned in a refractory lined combustor which had been previously used to conduct test burns on a copper containing waste. Subsequent studies did not result in yields approaching these levels; however, they did reveal the significant role of copper in increasing observed yields.

The most important result is that chlorinated dioxins were observed at all. Gas-phase chemistry and kinetics suggests that the chlorine should be eliminated first from the organics and largely fluorinated PICs would be observed since carbon-chlorine bonds are weaker than carbon-fluorine bonds. The explanation of these results may lie in the realm of surface induced reactions. It is well documented that HF, F2, and fluorinated organics etch silica. The etching is caused by the reaction of F with the hydrogen on the silica surfaces. Thus it would appear that fluorine may be removed from the organic at the same time that the organic is chemisorbed to the surface. This surface chemisorption can then lead to further reaction and dioxin formation, especially in the presence of copper or copper chlorides.

In combination with the chlorinated and brominated hydrocarbon data in the PIC analyte study, these data suggest that the trends in normal gas phase chemistry may be reversed by surface catalysis, the explanation being that bonds of Br, Cl and F with silanol groups are progressively stronger than with organic carbon groups. This is an important phenomena deserving of further study. Fundamental studies are needed that might best be carried out on very small gas phase and surface catalysis reactors where the confounding effects of large scale combustors are absent.

4.1.5 Bioassay Characterization of Incineration Emissions

This project compares the mutagenicity and carcinogenicity of various types of combustion effluents. Both the Ames test and the mouse papilloma tests are relatively simple and inexpensive evaluations of limited aspects of mutagenicity and of tumorigenicity, respectively. While the Ames test suggests that there are no major differences in combustion emissions and that incinerators are on the low end of the test scale, the Ames test is not very sensitive for chlorinated hydrocarbons. If chlorinated hydrocarbons could be considered, the results of the present test series might be different. More importantly, it has been amply demonstrated that the mutagenic potency as measured in the Ames test does not correlate with carcinogenic potency as measured in conventional life-time bioassays for carcinogenicity. The mouse papilloma assay has much more applicability to the present problem, but even this methodology is not generally recognized as being definitive. Studies on the potential biological effects of combustion products require a great deal of further investigation to allow definitive conclusions.

The Subcommittee recognizes that there are no direct bioassay data on the carcinogenicity of combustion products, even though this information is very important for the risk management of incineration and combustion processes. The Subcommittee also recognizes that direct bioassays of combustion products are technically extremely difficult. Nevertheless, the Subcommittee urges the Agency to pay more attention to the development of experimental data for the best scientifically defensible risk assessments for combustion and incineration products.

4.1.6 Monitoring and Control of PICs from Incinerators

Two portions of this project were discussed. The first was the development of an on-line GC for use in emission testing instead of the routine VOST analysis. With the on-line GC, researchers hope to obtain real-time analysis of 20 VOCs with 45 minute sample turnaround time. The unit was included as part of the joint DOE/EPA CEM testing program at the Incineration Research Facility. The results of this program were not presented. The development of continuous or near-continuous monitors is clearly important in the determination of what's coming out of the stack at any given time. However, the Subcommittee felt that, while the development of the on-line GC met the Agency's needs and could potentially be a useful tool, the laboratory now needs to compare this technology to other mass spectrometry technologies.

The second part of this project dealt with using artificial intelligence to control transient organics from hazardous waste incinerators. The investigators are applying fuzzy logic controls to reduce transients; this is done by injection of oxygen into the secondary combustion chamber. The funding for this project came from internal laboratory funds which are used as a method of "trying out" ideas from the scientists. It

is worthwhile to test these ideas and to encourage those involved to maintain a creative edge. The reduction of emissions from combustors and incinerators is certainly an important issue and the laboratory has submitted a proposal with Midwest Research Institute, the University of Kentucky, and Acurex Company to NSF to develop this work. Even technically promising programs such as this one need to be carefully evaluated within the strategic plan of the laboratory.

4.1.7 Mixing Characterization of Transient Puffs in a Rotary Kiln Incinerator

This project was a collaborative effort with the University of Arizona, Sandia National Laboratory, and EPA. The project focused on the understanding of the transient mixing in the gas phase of waste materials in the primary combustor zone of a rotary kiln. The approach was to use a cold flow physical model (built on the same scale as the EPA rotary kiln simulator) and then predict the average concentration and concentration fluctuation profiles using multiple computer simulations based on Kerstein's Linear Eddy Model Approach. These predictions were compared to the experimental data and used to investigate the mixing of the kiln.

The Subcommittee found that this project represented good collaborative effort with others and leveraging of funds. The approach takes the fundamental research of others and uses it to meet a goal of the laboratory (reduction of transient puffs in incinerators). In contrast with the project looking at mixing in the afterburner, this project is fundamentally based and therefore has the probability of application to full-scale systems.

4.2 Understanding Metal Transformations and Determining Metal Control

The research which has been conducted has attempted to understand metal transformations and the effects of certain parameters on the behavior and fate of metal aerosol. The investigators have used sorbents to control the metal emissions at high temperatures. Specifically, cadmium and lead have been studied. In a second project, the research has attempted to identify the partitioning of chromium to chrome (VI). Finally, the effectiveness of sorbents for mercury control is also being studied. This area is also of importance to the Agency. For the most part the projects are obtaining needed research information. Some collaboration was demonstrated but it was limited and integration with others could be expanded. Projects are meeting short-term needs.

4.2.1 Metal Aerosol Formation and High Temperature Control by the Sorbents

This work has been done in collaboration with the University of Arizona, MIT, and the University of Cincinnati. The issue of metal transformation is certainly one that is important to hazardous waste incineration and other combustion sources any time a metal-bearing material is burned. Metal compounds tend to contribute to risk assess-

ment and frequently are the most important compounds besides dioxins. The conclusions have been that toxic metals can be removed from the submicron fraction through the interaction with sorbents and two high temperature mechanisms have been identified. The effect of chlorine has also been studied. The future work will concentrate on understanding the interactions with other metals (besides lead and cadmium) and the effects of metal mixtures and other interfering elements, such as chlorine and sulfur. Model development and process scale up are also anticipated.

The work has lead to some significant mechanistic results which can be used in determining the interaction of metals with certain sorbent components; however, while investigating the control of toxic metals emissions is clearly a mission of this branch some effort to also obtain fundamental information would be useful and is needed. The research should be directed to include the investigation of the mechanisms and kinetics of reactions in combustion systems. In addition, the sorbent research should consider that the use of sorbents simply transfers the metals problem from a gas-phase to a solid-phase. A future direction of the research should look at the disposal options for the sorbents and the leachability of the metals from the sorbents (some of this work has already taken place).

As a general comment, the Subcommittee noted that the laboratory has the necessary equipment for conducting this type of research and is highly qualified. They have clearly positioned themselves in terms of experimental capability and capable researchers to be one of the leaders in the area of aerosol formation research.

4.2.2 Chromium Partitioning in Incineration Environments

This project was a result of direct support to OSW. The objectives were to explore the behavior of chromium (Cr) in combustion environments and examine Cr speciation as a function of chlorine and sulfur concentration and initial Cr valence. This work is extremely important in support of OSW for the Waste Minimization and Combustion Strategy. Presently, RCRA requires all the Cr to be assumed to be Cr(VI). Based on this assumption, Cr emissions often drive health risk assessments. The conclusions found that without chlorine, 2% or less of the total Cr existed as Cr (VI). In the presence of Cl, this increased to between 5-8% of the total. Given this result, the consideration of all the chrome to be Cr (VI) is questionable.

The results of this project clearly support OSW's needs for the Waste Minimization and Combustion Strategy. Again, if the laboratory had not developed the needed competency in this area, the work could not have been completed in such a timely manner for OSW.

4.2.3 Volatile Metal Control: Mercury

This project is investigating the control of mercury using sorbents. Three bench top reactors have been developed for elemental mercury, HgO, and $HgCl_2$. Future work will examine the reactivity, characterization, and regenerability of carbons; mass transport and kinetic limitations; and lime-based sorbents. There is ongoing development of an on-line monitor for oxidized mercury species.

The mercury projects are important, especially with regard to MSW combustion. The Energy and Environmental Research Center (EERC) in North Dakota has a large center in Air Toxics and is presently examining sorbent capture of mercury and analytical techniques. While their focus is more toward pilot scale, the extent of interaction between the two groups was not apparent. The Subcommittee encourages that the investigators interact with this group.

4.3 Multifuel Combustion

The laboratory presented the need for a multi-fuel combustor and the details of the design. The system has been installed and is presently in the shake down stages. As stated previously, one way that pollution prevention might impact incineration issues is that as industry and the public increase their waste minimization effectiveness, the composition of combustible hazardous waste streams will change. These changes may impact the current emissions that are expected from MSW combustion systems. The Subcommittee feels that the research is worthwhile and the facility will be useful; however, since the laboratory does not have a strategic plan and a base source of funding for the facility, it is questionable what the research direction might be. The Subcommittee recommends that a carefully thought out research plan be drawn up which fits the strategic plan of the laboratory.

4.4 Incineration Research Facility (IRF)

Two projects were presented from the IRF--The Comparative Evaluation of Continuous Emission Monitors and Low Temperature Desorption in a Direct-Fired Kiln. The results from the first project were not presented, because it is still under way. The results of the second project were presented and discussed. The tests were completed to determine the effect of treatment temperature, treatment time, bed depth, solids agitation, and moisture content on the evolution of hydrocarbons and metals. The Subcommittee felt that the results were useful and should be used in conjunction with a model to more fully understand some of the heat transfer effects which were shown.

Because the IRF is being closed, the Subcommittee did not see that further detailed comments would be of use.

5. CONCLUSIONS AND RECOMMENDATIONS

The Subcommittee felt that the laboratory has the equipment, facilities, and capabilities to be an asset to the Agency. The issues which they are investigating are timely and important. However, due to the limitations described in section 3.1, the program's strategic direction must be narrowed by developing a strategic plan and setting priorities. Given the budget limitations, it is no longer sufficient to be a world class facility in terms of productivity, relevance, timeliness, and quality. Consideration must also be given to narrowing the program to what EPA can uniquely do with its facilities. Each project should be re-evaluated with criteria which will meet the strategic needs of the laboratory versus just responding to a funding source's needs.

The Subcommittee's major recommendations were:

a) The group should foster more interaction with other researchers . This interaction should be in the form of collaborative research projects where both EPA and outside scientists are involved from development of the concept through to completion of the work. Collaboration is important because it can strengthen areas where the laboratory does not have expertise. No one research group can have all the expertise and facilities relevant to combustion. Collaborative efforts are important because they make it possible for both groups to do research that neither could do alone.

b) The group should formalize their strategic plan to help determine criteria for judging the projects which are underway. In addition, the strategic planning should incorporate the role of incineration and combustion in pollution prevention. Prevention can be addressed in two areas: i) changes in technology to reduce the reliance on end-of-pipe control technology, and ii) segregating the waste stream to isolate, and perhaps pretreat, constituents that are known to have a negative impact on the emissions from combustion and incineration systems. The impact of the effect of changing waste streams, a result of waste minimization and pollution prevention activities, needs to be investigated with regard to its potential impact on the emissions from these systems.

c) The Agency should consider the combustion program as a "core competency" and support it as one. Although the importance of incineration will vary under different policies, combustion and incineration research should remain part of the Agency's core research program because of the dependence of society on combustion. Necessary funding will allow this group to continue to meet these long-term as well as short-term needs of the Agency.

d) The SAB Research Strategies Advisory Committee (RSAC) should look at the low R&D to capital equipment budget ratio and determine if the present ratios are acceptable to enable the program to continue with viable projects as well as obtain the necessary equipment.

APPENDIX A - DOCUMENTS REVIEWED

1. Letter from Dr. Hall to Subcommittee of August 28, with enclosures:
   A. Agenda
   B. Incineration Program Background
   C. Relevant Bibliography
   D. 14 Papers by RTP Laboratory Scientists
   E. Eight CVs for RTP Laboratory Scientists
2. Letter from Dr. Thurnau to Subcommittee of August 30, with enclosures
   A. IRF: Incineration Research Facility (EPA-600/M-89/027, November 1989)
   B. Operations and Research at the U.S. EPA Incineration Research Facility: Annual Report for FY93 (EPA/600/R-94/091, June 1994)
   C. Operations and Research at the U.S. EPA Incineration Research Facility: Annual Report for FY94 (EPA/600/R-95/071, June 1995)
3. Handout by the Laboratory provided at the meeting including agenda, roster (with some errors) and copies of overheads used by EPA speakers in their presentation. This roster gives an incorrect address for Dr. French and incorrectly identifies Dr. Costner, a public commentator, as an invited participant.
4. Preliminary written public comments from Pat Costner dated August 26, 1995 (8:21 a.m.)
5. "One-page" Project Description, August 1, 1995
6. Materials distributed September 12:
   A. Gas Phase Mixing of Transient Organics (punched for inclusion into notebook, #5 above.
   B. Compilation of MWC Dioxin Data, OAQPS, July 27, 1995
   C. Dioxin Emissions--Effect of Chlorine/Time/Temperature Relationships at 300 degrees C, Joseph J. Santoleri
   D. Continuous Emissions Monitoring Demonstration Program, Dan Burns
   E. Effect of Staged Combustion on PIC and Potential Dioxin Production During Chlorocarbon Combustion, Tai-Gyu Lee and others
   F. Effect of High-Levels of SO2 Emissions on the Analysis of Polycyclic Aromatic Hydrocarbons (PAHs) from Coal-Fired Utilities, Hani S. Karam
   G Effect of High-Levels of SO2 Emissions on the Analysis of Chlorinated Dibenzo-p-dioxins (PCDDs) and Chlorinated Dibenzofurans (PCDFs) from Air Emission Sources, Hani S. Karam
   H Copies of the overheads of Brian K. Gullett
   I. Incineration Program Resources FY90-96, punched for inclusion in the binder, provided at the request of the Subcommittee
7. Materials handed out September 13: Copies of overheads used by Bob Thurnau in his presentation.
8. Memorandum from Robert Thurnau, "Peer Review Publications Relative to the SAB Evaluation," October 3, 1995

9. Memorandum from Blair Martin, “Background Information for SAB Review of APPCD Incineration Program,” October 12, 1995

APPENDIX B - ACRONYMS AND ABBREVIATIONS

AEERL	Air and Energy Engineering Research Laboratory
APPCD	Air Pollution Prevention and Control Division
AI	artificial intelligence
Br	bromine
CEM	continuous emission monitor
CFC	chlorofluorocarbon
Cl	chlorine
Cr	chromium
CRB	Combustion Research Branch
DOD	Department of Defense
DOE	Department of Energy
EEC	Environmental Engineering Committee
EERC	Energy and Environmental Research Center in North Dakota
ESP	Electrostatic Precipitators
F_2	Fluorine
HF	Hydrogen Fluoride
IRF	Incineration Research Facility
MSW	Municipal Solid Waste
MWC	Municipal Waste Combustor
NEHSRC	Northeast Hazardous Substance Research Center
NRMRL	National Risk Management Research Laboratory
NSF	National Science Foundation
OAQPS	Office of Air Quality Planning and Standards
ORD	Office of Research and Development
OSW	Office of Solid Waste
PAH	polycyclic aromatic hydrocarbon
PCD	polychlorinated dioxin
PCDD/PCDF	chlorinated dibenzo-p-dioxin/furan
PCF	polychlorinated furan
PIC	product of incomplete combustion
PM	particulate matter
RCRA	Resource Conservation and Recovery Act
VOC	volatile organic hydrocarbon
VOST	volatile organic sampling train

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